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PACKAGING SYSTEMS

Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks?

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Abstract

Background, aim, and scope This paper presents the results of the LCA of wine production in the region of La Rioja (Spain). The aim of this study was twofold: to identify the most critical life cycle stages of an aged Spanish wine from the point of view of the associated environmental impacts and to compare its environmental performance with that of other wines and beers for which comparable information could be found in the scientific literature. All the product's life cycle stages were accounted for, namely: grapes cultivation (viticulture), wine making and bottling, distribution and sales, and disposal of empty bottles.

Materials and methods Foreground data were directly obtained from wine producers, farmers, and oenologists; background data were instead sourced from the GaBi professional database. In order to limit the uncertainty and subjectivity of the results, the choice was made to only employ midpoint indicators of environmental impact (global warming potential (GWP), acidification potential, eutrophication potential, photochemical ozone creation potential), in addition to gross energy requirement (GER) and water demand (WD). The calculated environmental indicators were allocated to the following co-products on the basis of the associated economic revenues: wine, pomace, lees, and press syrup. The avoided impacts associated to electricity generation were accounted for according to the displaced marginal technology.

Results The GWP of Rioja wine was found to lie between 900 and 1,000 g(CO_2-eq)/bottle, depending on the assumed distribution scenario. GER is around 8–9 MJ/bottle, and WD is approximately 5 kg/bottle. The most relevant life cycle stages from the point of view of most of the considered impact categories were found to be viticulture (and fertilizer use in particular) and the production of glass for the bottles. Transportation of the wine and final disposal of the empty bottles cumulatively account for a maximum of 30% of the overall impact, depending on the specific indicator and the assumed distribution scenario.

Discussion The analysis appears to be in good agreement with previous literature studies, the results of which lie within a comparatively narrow range. Within such range, the more upmarket Rioja wine can arguably be seen as providing a greater net benefit to the economy per unit of impact.

Conclusions The present analysis has shed light on which are the two main environmental bottlenecks in the life cycle of industrialized wine, namely viticulture and glass production for bottle manufacture; GWP results are in the same range as those from previous literature studies. New insight is also provided on a possible measure of "economic return on environmental investment."

Recommendations and perspectives As it stands, the study presented here is arguably among the most complete and transparent analyses in the alcoholic beverage sector. It could be further enhanced at a later stage by also including those secondary sub-processes which were cut off due to lack of available data (including herbicides and pesticides). As for cross-comparability, it would be recommendable for all authors to never omit presenting their results in terms of transparent, disaggregated impact indicators.

Keywords Alcoholic beverages · Bottles · LCA · Life cycle assessment · Viticulture · Wine

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1 Background, aim, and scope

The production of crianza (i.e., aged) wines and other gourmet alcoholic beverages often represents an important cultural heritage, as well as a source of economic revenues, for many European countries. However, there are still comparatively few literature studies in which the environmental effects of wine production are investigated from a complete life-cycle perspective (Garnett 2007).

This paper presents the results of an original study of wine production in the Spanish region of La Rioja, including all the product's life cycle stages, namely: cultivation of grapes, wine making and bottling, distribution and sales, and disposal of empty bottles. The initial planting of the grapevines and their eventual disposal at the end of their life cycle were excluded, given their long average life span of 30 to 70 years. All data refers to production year 2005.

The aim of the study was twofold: on the one hand, to identify the most critical life cycle stages of wine production from the point of view of the associated environmental impacts; on the other hand, to compare the overall environmental performance of a typical Spanish gourmet wine with that of other key alcoholic table beverages (wines and beers) for which comparable information could be found in the scientific literature.

The Rioja region is one of the most important European sources of aged wine production, hosting many world-renowned producers of white, rosé (pink), and red Denominación de Origen Calificada (DOC, i.e., Qualified Designation of Origin) wines. The focus of this study was not on any specific wine produced under a given brand; in order to produce results which would be representative of the largest share of the wines produced in the region, the following two basic assumptions were made:

- The wine would be a red "crianza," i.e., a red wine that is nurtured for a minimum of 2 years, at least one of which in traditional oak barrels. In 2008, the crianza wine represented the 40% of the total amount of commercialized Rioja wines (Consejo Regulador DOC Rioja 2008).
- The vineyards would not be artificially irrigated.

Among the few literature studies that could be used for comparative purposes, the following three were selected: a life cycle assessment of wine produced in the Spanish regions of Aragón and La Rioja (Aranda et al. 2005), a report by the South Australian Wine Industry Association (SAWIA 2004), and a life cycle assessment of beer production in Greece (Koroneos et al. 2005). Two other studies were also found to be potentially interesting, but could not be used for comparative purposes, since they only reported results in terms of aggregated single-score indicators, without allowing for a transparent evaluation of the individual contributions to the considered impact categories (Cordella et al. 2008; Talve 2001).

2 Materials and methods

2.1 Life cycle inventory, assumptions, and allocation

The analysis was performed with the GaBi software package (GaBi 2007a), and the bundled professional database (GaBi 2007b) was employed as the principal source of background data. Data for the foreground system were instead directly obtained by the authors from a number of wine producers, farmers, and oenologists from the Rioja region and can therefore be considered of very high quality according to the criteria of reliability, completeness, and temporal and geographic representativeness.

The life cycle of wine is organized in four main stages: (1) viticulture (i.e., cultivation of the grapes), (2) wine making and bottling, (3) distribution and sales, and (4) disposal of the empty bottles. A block diagram of the whole life cycle is illustrated in Fig. 1.

The chosen functional unit for the study was one bottle (0.75 L) of red "crianza" wine. Approximately 0.27 ha of land are required for the production of 1,000 L of wine, and an average of 500 kg/ha of inorganic fertilizer and 3,000 kg/ha of organic fertilizer (sheep dung) are used each year. The local-scale emissions due to fertilizer use were specifically included in the life cycle inventory by means of an appropriate distribution model (Milà i Canals 2003), based on an average soil retention factor of 60% for inorganic fertilizer. The transport of the fertilizer was included in the model, as was that of the harvested grapes to the wine production facilities.

The life cycle of the valuable oak barrels that are used for nurturing the wine was thoroughly assessed (growing of oaks and production of barrels) and included in the analysis, since it was found to have a significant impact on the overall results. The barrels have a durability of 84 months, out of which an average of 18 months are used for the nurturing of the Rioja wine analyzed here; they are then used for lower quality wines for the remaining part of their useful lifetime. It can be maintained that their impacts are to be allocated proportionally to the shares of their lifetime for which they are used for each product system. As a consequence, only 21% of the environmental burdens associated to the barrels were allocated to the system under study.

Common 750 mL green glass bottles were considered to be employed, each weighing 400 g; corks, labels, and tin caps were also included in the analysis. The bottles were assumed to be manufactured out of 60% recycled glass

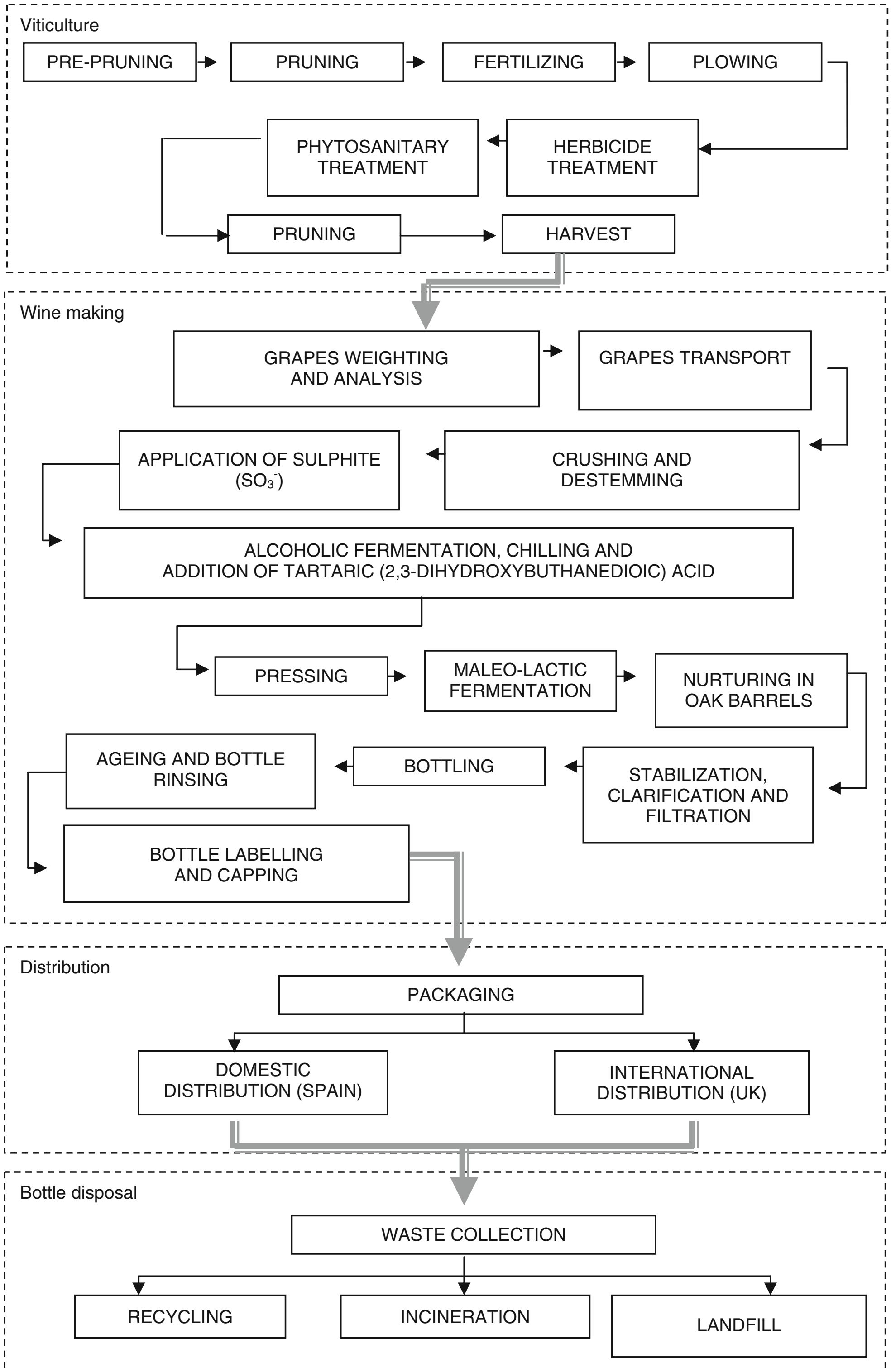


Fig. 1 Block diagram of life cycle of Rioja wine

(Ecovidrio, personal communication). They were then assumed to be packaged in 12-bottle cardboard boxes and sent out by lorry in standard European pallets.

Two distribution scenarios for the wine bottles were analyzed in parallel, i.e., national distribution within Spain (average distance=450 km) and international distribution to the UK (average distance=1,350 km, i.e., Logroño to London).

Separate assumptions on the relative shares of waste treatment options were also made, in order to be consistent with the two distribution scenarios: in particular, in Spain 53% of the glass is landfilled, 42% is recycled, and 5% is sent to

incineration (Ecovidrio, personal communication; INE 2001); instead, in the UK 69% of the glass is landfilled, and only 31% is recycled (Waste Online 2005). Since 60% of all the input glass is secondary, there is little room for additional environmental credits associated to end-of-life recycling.

The following sub-processes had to be cut off from the analysis because of lack of available data and/or their negligible importance:

- Production and eventual decommissioning of wine-making machinery and related equipment (the associated impact was assumed to be negligible when divided by the total product throughput)
- Production of herbicides and pesticides
- Emissions caused by the application of herbicides and pesticides
- Production of organic fertilizer
- Production of egg whites (used in the wine clarification step)
- Pre-treatment and transport of the required process water
- Waste water treatment

Table 1 lists the main direct inputs to the product system under study, organized under the following headings: viticulture, wine making, barrel production, and bottle production.

During the wine-making stage, three economically valuable by-products are produced besides wine itself: pomace, lees, and a thick syrup produced by pressing the solid residues of the first fermentation step. ISO standard 14044 (2006) recommends to avoid the allocation of environmental loads whenever possible, through either system subdivision or expansion. However, in the analyzed case study neither of these strategies was viable: on the one hand, the grapes residues and fermentation sediments are obviously impossible to produce separately, and therefore it would make no sense to divide the wine-making process into two or more independent sub-processes; on the other hand, not enough detailed information could be obtained during the course of the study on the alternative products that could be replaced by pomace, lees, and press syrup, making a proper system expansion impossible. The choice was then made to allocate the environmental load of viticulture and wine making to all four by-products, based on their relative economic values (Table 2). This type of allocation reflects the actual thrust behind the whole wine industry much better than either mass- or energy-based allocation, since the principle product by far is obviously wine itself, and not any of the other by-products.

Lastly, incineration of part of the wastes produced in the wine life cycle leads to some electricity generation, which can be accounted for as an additional by-product. In this case, system expansion was viable and was therefore employed as a preferred alternative to allocation. According to the methodology proposed by (Weidema 2001), the marginal technology for electricity generation should be assumed to be displaced, in order to calculate the avoided impact to be subtracted from the life cycle of the analyzed product (marginal technologies are defined as the technol-

Table 1 Main direct inputs to the product system under study

Phase	Input	Unit	Amount per functional unit
Viticulture	Land	ha	0.002
	Diesel (workers transportation)	L	0.002
	Diesel (machinery)	L	0.005
	Inorganic fertilizer	kg	0.100
	Organic fertilizer	kg	0.601
	Transport of fertilizers	tkm	0.225
Wine making	Grapes	kg	1.273
	Water (cleaning)	L	1.070
	Water (process)	L	0.010
	Electricity	MJ	0.373
	Sulphite	kg	0.0001
Barrel production	Oak wood	kg	0.111
	Steel	kg	0.001
	Transport	tkm	0.491
Bottle production	Green glass bottle	kg	0.400
	Label	kg	0.002
	Cork	kg	0.003
	Cap	kg	0.005
	Transport	tkm	0.043

All data are referred to 1 FU (0.75 L of wine)

Table 2 Unit prices of system by-products and derived allocation factors (1 FU=0.75 L of wine)

Co-product	Price	Price per functional unit	Allocation factor
Wine	4.2 €/L	3.15 €	0.98493
Pomace	0.05 €/kg	0.014 €	0.00444
Lees	0.008 €/kg	0.0006 €	0.00018
Press syrup	0.3 €/L	0.0333 €	0.01042

All prices are wholesale at the wine farm

ogies actually affected by small changes in demand). For the current situation in Spain, electricity produced from natural gas and from fuel–oil was identified to be the most representative marginal technologies.

2.2 Impact categories

In order to limit the uncertainty and subjectivity of the results, the choice was made to only employ midpoint indicators of environmental impact in this study. For the same reasons, the clear choice was also made to refrain from performing the optional steps of normalization and weighting, in order to allow the results of the two considered scenarios to remain comparable among themselves, and also with the results of independent analyses of similar products in the scientific literature. In fact, presenting the results of an LCA in terms of some form of aggregated single-score indicator (without at the same time providing disaggregated, category-specific indicators) severely hampers the transparency of the study. It also prevents any comparison to alternative scenarios or products from being ISO compliant (2006).

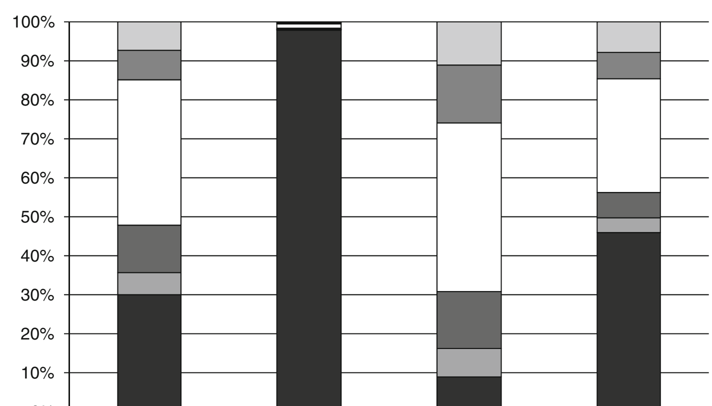
The following emission-related impact categories were selected as the most relevant for the intended goals of the analyzed case study: global warming potential (GWP), acidification potential, eutrophication potential, and photochemical ozone creation potential. The employed characterization factors were those included in the widely accepted CML 2001 method (Guinée 2002).

The inclusion of the human toxicity and eco-toxicity impact categories could have potentially provided valuable additional insight into the environmental performance of the analyzed system; however, it was decided to leave them out at this stage because of the large degree of uncertainty in the associated characterization factors, as well as the lack of reliable information on the actual environmental fate of the potentially toxic chemicals (pesticides and herbicides) that are used in the viticulture stage, in the specific conditions of the Rioja soil.

Lastly, gross energy requirement (GER, in terms of primary energy) and water demand were also considered as indirect measures of resource depletion-related environmental impact.

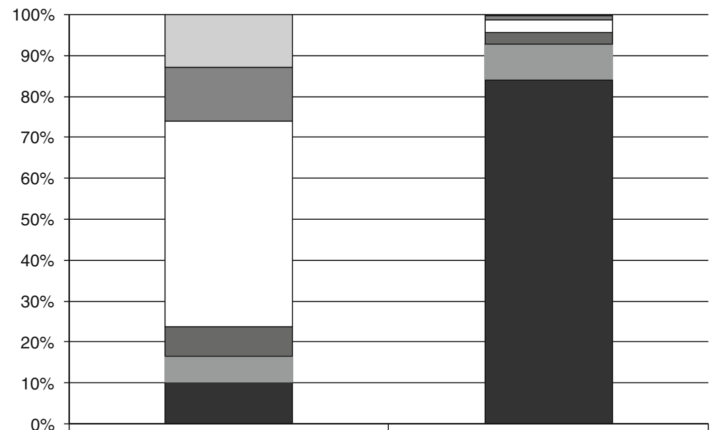
3 Results

Figures 2 and 3 present a breakdown of the calculated cradle-to-grave impact indicators for the following sub-product systems: viticulture, wine making, barrel production, and bottle production.



	AP (g SO2-eq/FU)	EP (g PO4-eq/FU)	POCP (g C2H4-eq/FU)	GWP (g CO2-eq/FU)
incremental impact for international (UK) vs. domestic distribution and disposal	0.51	0.09	0.04	85
domestic (Spain) distribution and disposal	0.51	0.11	0.06	76
bottle production	2.6	0.3	0.17	319
barrel production	0.8	0.1	0.06	72
wine making	0.4	0.0	0.0	40.1
viticulture	2.1	30.5	0.03	503

Fig. 2 Results in terms of emission-related impact categories (1 FU=0.75 L of wine)



	GER (MJ/FU)	WD (kg/FU)
incremental impact for international (UK) vs. domestic distribution and disposal	1.28	0.010
domestic (Spain) distribution and disposal	1.3	0.06
bottle production	5.0	0.1
barrel production	0.7	0.1
wine making	0.6	0.4
viticulture	1.0	4.0

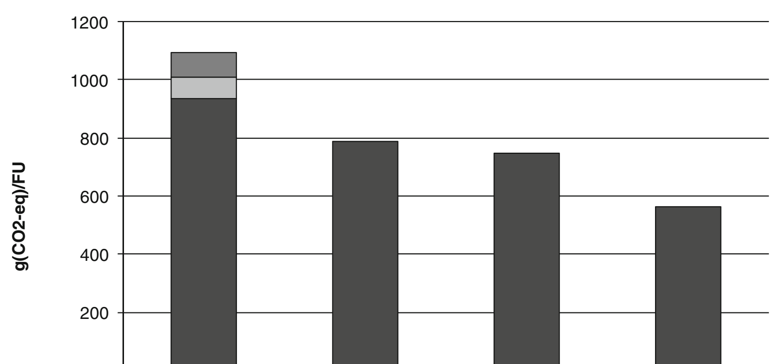
Fig. 3 Results in terms of resource depletion-related impact categories (1 FU=0.75 L of wine). *GER* gross energy requirement, *WD* water demand

Then, Fig. 4 compares the results of the LCA in terms of GWP to those of three selected literature studies: one for an average Spanish wine (Aranda et al. 2005), one for an average Australian wine (SAWIA 2004), and one for a typical lager beer produced in Greece (Koroneos et al. 2005). All results are expressed in terms of grams of CO_2-equivalent per functional unit (FU), and have been rescaled to the same FU, i.e., 0.75 L of bottled beverage. The rationale behind this comparison was to provide a frame of reference for this study, as well as to verify the extent of the variance among these four relatively similar products. The comparison was made at the “cradle to gate” level, since sufficiently detailed information of the assumptions behind the distribution and disposal steps was lacking for the other studies.

In all figures, the distribution and disposal steps are therefore indicated separately for the LCA of the Rioja wine, and the difference between the domestic and international distribution scenarios is expressed in terms of the additional incremental impact associated to the latter with respect to the former.

4 Discussion

Almost one half of the greenhouse gas emissions (expressed as CO_2-equivalent) associated to the whole life cycle of the Rioja wine were found to be released in the



	Rioja 'crianza' wine (this work)	Avg. Spanish wine (Aranda et al., 2005)	Avg. Australian wine (SAWIA, 2004)	Greek lager beer (Koroneos et al., 2005)
incremental impact for international (UK) vs. domestic distribution and disposal	85			
impact for domestic (Spain) distribution and disposal	76			
'to gate' impact	934	789	747	563

Fig. 4 Comparison to results from selected literature studies, in terms of global warming potential (1 FU=0.75 L of beverage)

viticulture stage. These are mainly due to the large release of dinitrogen monoxide (N_2O), a potent greenhouse gas, during the fertilization of the grapevines. Glass production for bottle manufacture comes in second in order of importance, as far as GWP is concerned. On the other hand, and somewhat contrary to what could be expected given the considerable weight of the full bottles, the distribution stage only accounts for approximately 7% and 15% of the total GWP, respectively, for the domestic and international distribution scenarios.

The acidification potential is principally caused by glass production (almost 40%) and by the ammonia and nitrogen oxide emissions caused by fertilizer use (30%). Glass production is also largely responsible (over 40%) for the photochemical ozone creation potential, while in this category the importance of viticulture is comparatively reduced (10%) and becomes similar to that of barrel production and distribution. On the other hand and as a consequence of fertilizer use, within the eutrophication category, virtually all (98%) of the impact takes place during viticulture.

The gross energy requirement indicator is dominated by glass production (50% of the GER over the whole life cycle). Finally, the vast majority (over 80%) of the cumulative water demand for wine production occurs in the viticulture stage, and specifically in the phytosanitary treatment step.

Comparing the results in terms of GWP to those from previous literature studies, a first general finding is that all four analyses appear to be in good agreement, producing results that are comprised within a relatively narrow range. In particular, on the basis of these results, the "cradle-to-gate" GWP of a generalized wine can be safely taken to be between 750 and 900 g (CO_2-eq) per bottle. The LCA of beer, instead, produced a marginally lower GWP figure (approximately −30% with respect to wine).

It is noteworthy that the global warming potential of a quality, nurtured wine was found to be only negligibly higher than that of more average wines produced in Spain and in Australia (in fact, such small discrepancies are more likely to be the result of slightly different assumptions or background data than a real indication of any meaningful difference in the environmental performance of the three wines). This goes to prove, at least to some extent, that economic value and perceived quality do not necessarily correlate with environmental impact. Pushing the envelope a little further, a tentative comparison in terms of "economic return on environmental investment" can be made between the analyzed Rioja wine and common lager beer. The average retail price of a Rioja "crianza" wine in Spain is 18.5 €/bottle, i.e., 24.6 €/L (after El Corte Inglés 2008); on the other hand, the average retail price of beer in Spain is reported to be 2.5 €/pint, i.e., 4.4 €/L (Pintprice 2008). Therefore, since a fine wine such as the Rioja one analyzed here is considerably more expensive than the average beer, it can be argued that it provides better "economic return on environmental investment," measured as the ratio of economic revenues to global warming potential. The calculated values for the Rioja wine and for beer are respectively 22 €/kg (CO_2-eq) vs. 6 €/kg (CO_2-eq). This comparison was based on the "cradle-to-gate" GWP, since the distribution and bottle decommissioning stages could not be included for the beer; however, based on our findings about the relative magnitude of the latter, the order of magnitude of the comparison can be reasonably assumed to stay valid even when these are included. Furthermore, if anything, the relative contribution of the distribution stage is likely to be higher for beer than it is for wine, since the former is usually sold in smaller (0.33 to 0.5 L) bottles, thereby implying a less favorable per-liter packaging efficiency.

In the domestic distribution scenario, the distribution and disposal stages cumulatively account for a relatively small portion (maximum 15%) of practically all environmental impact indicators. However, the alternative scenario for international distribution to the UK invariably produced almost double impact indicators across the board, which is due not only to the larger transport distance, but also to the lower percentage of end-of-life glass recycling in the UK vs. in Spain. Extrapolating these results, a much larger and potentially serious contribution to the life cycle environmental impact of wine may emerge, when it is transported over very long distances and/or to countries where the disposal of the empty bottles is carried out in a less environmentally sound way.

5 Conclusions

The detailed life cycle analysis of the Rioja wine preformed here has shed light on which are the two actual environmental bottlenecks in the life cycle of industrialized wine, namely viticulture and glass production for bottle manufacture.

At the other end of the scale, the distribution of the wine bottles was found to have but a minor influence on the life cycle environmental performance of the wine, especially in the domestic distribution scenario, which is characterized by comparatively shorter transport distances. The situation may change to an extent in a long-range (e.g., intercontinental) transport scenario.

A comparison with three previous literature studies, in terms of GWP, has shown that all beverages (Spanish wine, Australian wine, and Greek larger beer) have comparable environmental impact, and as a consequence, the more upmarket Rioja wine can be seen as providing a greater net benefit to the economy per unit of impact.

6 Recommendations and perspectives

As it stands, the study presented here is arguably among the most complete and transparent analyses in the alcoholic beverage sector. Not only does it include all the life cycle stages of wine production, but it also goes to great lengths to address specific sub-processes such as for instance the local-scale emissions due to fertilizer use and the production and end of life of the oak barrels used for nurturing the wine. Still, the comprehensiveness of the LCA could be further enhanced at a later stage by also including those secondary sub-processes which were cut off from the analysis due to lack of available data, such as the life cycle of the employed herbicides and pesticides. Consequently, it would also be interesting to extend the range of considered impact categories to soil and freshwater eco-toxicity (even though the robustness of the latter is still comparatively lower than the other categories considered here).

Last but not least, as a general remark, it is the authors' opinion that it would be recommendable to reach a wide consensus in the LCA community never to omit the presentation of LCIA results in terms of disaggregated midpoint impact indicators. This is in fact the only way to enable a meaningful comparison among different case studies within the same sector, without concealing possibly relevant differences in individual impact categories, or, worse, incurring in the possible misinterpretation of the results themselves.

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